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EXPERIMENTS ON THE DIGESTIBILITY OF WHEAT BRAN IN A DIET WITHOUT WHEAT FLOUR.[1]

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REVIEW OF PREVIOUS INVESTIGATIONS.

Wheat in some form constitutes a very large proportion of the average dietary. The larger part of the wheat used for human food is consumed in the form of bread, which ordinarily is prepared from one of three common types of wheat flour—white flour (commercially known in this country as standard patent), entire or whole-wheat flour, and graham flour. The importance of wheat in the American dietary is readily appreciated when it is noted that in normal times the annual per capita consumption is approximately 5 bushels;[2] it has been estimated[3] that excluding wheat breakfast foods, macaroni, spaghetti, and similar foods, and referring only to the three common flours, patent, entire, and graham, they supply 20 per cent of the protein, and 26 per cent of the carbohydrate of the average dietary. In times of stress even greater reliance is placed on bread, and it is a matter of repeated observation that those of relatively small incomes tend to make bread a predominating portion of the diet. With the outbreak of the war, and the prospect of a diminished supply of some food materials, the question of a more complete milling of wheat

[1] Prepared under the direction of C. F. Langworthy, Chief, Office of Home Economics.
[2] U. S. Dept. Agr. Bur. Crop Estimates Rept., 3 (1917), No. 10, p. 99.
[3] U. S. Dept. Agr. Office Expt. Stas. Circ. 110 (1911), p. 26.

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and the effect of a modification in milling upon the nutritive value of the resulting flours assumed unusual importance to those concerned with the feeding of large numbers of people.

In the modern milling processes the germ, together with a large portion of the outer layers of the wheat kernel, is removed. The removal of the germ, which contains practically all of the wheat fat or oil, lowers the energy value somewhat but improves the keeping quality of the flour. Chemical analysis shows that the outer layers of the wheat kernel, also removed in the preparation of patent flour, contain protein, carbohydrate, and mineral matter, constituents which are necessary for the proper nutrition of the body. Very recently it has been demonstrated by McCollum and coworkers[1] that the wheat germ contains Fat-soluble A, and this and the outer layers of the wheat kernel some Water-soluble B,[2] both of which are essential in the dietary to prevent nutritional diseases. These substances are present, it is true, in limited amounts, insufficient for the needs of the body during its entire lifetime and yet in amounts not wholly negligible. With these facts in mind the question very naturally arises whether it is not desirable to include the entire kernel in wheat flour rather than to utilize only the interior portions of the kernel. In order to arrive at an intelligent solution of this question it appears necessary to consider the large number of factors influenced by a modification of milling conditions. Of special interest to the student of nutrition is the effect on the digestibility of wheat flour of including a part or the whole of the wheat germ and the outer layers of the wheat kernel in the flour.

Since wheat flours contain very little fat, interest has been centered on the digestibility of the protein and carbohydrate supplied by the different types of wheat flours; and in general the digestibility of wheat protein has received the most attention.

The earlier work of the Department of Agriculture included a large number of studies of the digestibility of wheat flours, prepared from both spring and winter wheats, and from wheat grown in different localities. In the tests referred to below, the wheat was milled so as to produce from the same lot of wheat, white (patent) flour representing 72 per cent of the wheat kernel, entire or whole-wheat flour representing 85 per cent of the wheat kernel, and graham flour representing 100 per cent of the wheat kernel.

Woods and Merrill[3] conducted 13 digestion experiments with white-flour bread in which the protein was 86.4 per cent and the carbohydrate 98.3 per cent digested, five experiments with entire-

[1] Jour. Biol. Chem., 25 (1916), No. 1, pp. 105–131, figs. 19; 28 (1916), No. 2, pp. 211–229, figs. 17.

[2] Jour. Biol. Chem., 24 (1916), No. 4, p. 493.

[3] U. S. Dept. Agr., Office Expt. Stas. Bul. 85 (1900), pp. 32, 33.

wheat bread in which the protein was 86.7 per cent and the carbohydrate 97.2 per cent digested, and six experiments with graham bread in which the protein was 77 per cent and the carbohydrate 92.4 per cent digested. In a later publication the same authors report[1] that the digestibility of white flour is 93.8 per cent for protein and 98.9 per cent for carbohydrate, that the digestibility of entire wheat flour is 80.8 per cent for protein and 96 per cent for carbohydrate, and that the digestibility of graham flour is 81.3 per cent for protein and 91.1 per cent for carbohydrate.

Snyder[2] in studies of the digestibility of wheat flours reports that the digestibility of white flour is 85.3 per cent for protein and 97.5 per cent for carbohydrate, that the digestibility of entire wheat flour is 80.4 per cent for protein and 94.1 per cent for carbohydrate, and that the digestibility of graham flour is 77.6 per cent for protein and 88.4 per cent for carbohydrate. In experiments made to determine the digestibility of hard spring and soft winter wheats, Snyder found that the digestibility of hard spring wheat[3] flours is 88.3 per cent for protein and 97.7 per cent for carbohydrate for white flour, 86.2 per cent for protein and 96.2 per cent for carbohydrate for entire wheat flour, and 82.8 per cent for protein and 91.5 per cent for carbohydrate for graham flour; he also found that the digestibility of flours prepared from soft winter Michigan wheat[4] was 92.8 per cent for protein and 98 per cent for carbohydrate for white flour, 85.7 per cent for protein and 92.9 per cent for carbohydrate for entire wheat flour, and 79.4 per cent for protein and 89.3 per cent for carbohydrate for graham flour.

In other studies to determine the digestibility of flours prepared from wheat grown in different localities Snyder[5] found that the digestibility of protein supplied by Oregon wheat flours was 84.9 per cent for protein and 98.2 per cent for carbohydrate for white flour, 71.1 per cent for protein and 94.1 per cent for carbohydrate for entire wheat flour, and 63 per cent for protein and 91.2 per cent for carbohydrate for graham flour, and that the digestibility of Oklahoma wheat flours was 90.9 per cent for protein and 97.7 per cent for carbohydrate for white flour, 79.6 per cent for protein and 90.5 per cent for carbohydrate for entire wheat flour, and 77.3 per cent for protein and 87.9 per cent for carbohydrate for graham flour.

Since in these tests made by the United States Department of Agriculture the diet was comparable, and, as far as possible, uni-

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 143 (1904), p. 32.
[2] U. S. Dept. Agr., Office Expt. Stas. Bul. 101 (1901), p. 33.
[3] U. S. Dept. Agr., Office Expt. Stas. Bul. 126 (1903), p. 29.
[4] U. S. Dept. Agr., Office Expt. Stas. Bul. 126 (1903), p. 45.
[5] U. S. Dept. Agr., Office Expt. Stas Bul. 156 (1905), p. 36.

form experimental conditions were maintained, it is perhaps fair to consider all of these digestion experiments as a group. The digestibility of white flour obtained by averaging the 31 tests noted above is 88.1 per cent for protein and 95.7 per cent for carbohydrate; the digestibility of entire wheat flour obtained by averaging the 23 tests is 81.9 per cent for protein and 94 per cent for carbohydrate; and the digestibility of graham flour obtained by averaging the 24 tests noted is 76.9 per cent for protein and 90.6 per cent for carbohydrate.

Considering these tests as a whole, it appears that the protein and carbohydrate are more completely assimilated from white flour than from entire wheat or graham flours, the last being the least assimilated; or in other words, the increasing of the amount of bran included in a flour is accompanied by a corresponding decrease in its digestibility.

A number of investigations have been conducted in European countries to determine the effect on digestibility of including more or less bran in the flours prepared from wheat and other cereals.

Among the earlier studies of the nutritive value of wheat is a study by Rubner,[1] who determined the digestibility of the protein present in three flours milled so as to contain 30 per cent, 70 per cent, and 100 per cent of the wheat kernel. He found that the protein of the 30 per cent flour was 79.3 per cent digested, the protein of the 70 per cent flour was 75.4 per cent digested, and the protein of the 100 per cent flour 69.5 per cent digested. Blyth[2] conducted a series of experiments to determine the digestibility of wheat meal (flour prepared from the entire wheat kernel) when eaten without the addition of other food materials. In one experiment of 29 days divided into three periods, during the first period of 8 days 81 per cent of the protein supplied by the 16 ounces of wheat meal eaten daily was digested, during the second period of 14 days 82 per cent of the protein of 20 ounces of meal was digested, and during the third period of 7 days 84 per cent of the protein of 28 ounces of meal was digested. In a second experiment of 7 days' duration in which the diet consisted of whole meal and distilled water, the subject digested 90 per cent of the protein supplied by the meal eaten, which varied from 16 to 22 ounces daily.

Pugliese[3] conducted studies to determine the effect of milling on the digestibility of wheat flour. He reports that the digestibility of the protein of flour containing 85 per cent of the wheat kernel is 10 per cent less than the digestibility of the protein of flour containing 75 per cent of the wheat kernel.

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[1] Ztschr. Biol. 19 (1883), pp. 45–100.
[2] Proc. Roy. Soc. [London], 45 (1888–89), No. 279, pp. 549–553.
[3] Rev. Gén. Sci., 26 (1915), No. 21, pp. 612–617.

It is sometimes contended that test periods of three or four days' duration are too short to give reliable data regarding the digestibility of foods. Newman and Robinson,[1] who question the accuracy of results of digestion experiments of only three days' duration, studied the relative digestibility of white flour and whole meal (flour prepared from whole wheat kernel) breads of which 700 to 800 grams were eaten with 600 cubic centimeters of milk and 30 grams of butter fat daily for a period of two weeks. As a result of four experiments in which, with one exception, the protein of white flour was more completely digested, they found that on the average the protein of white flour was 89.3 per cent digested while the protein of whole meal was 85.9 per cent digested. They also report that the digestibility of the protein of a wheat meal (92 per cent of the kernel) was 76.7 per cent as compared with a digestibility of 80.4 per cent for the protein of another wheat meal (88 per cent of the wheat kernel).

Experiments conducted by Hindhede[2] to determine the relative digestibility of coarsely ground wheat as compared with ordinary white flour are not open to this criticism, since they were of seven months' duration. He found that the protein of coarsely ground wheat (bread) eaten with margarine was 75 per cent digested while the protein of ordinary wheat flour eaten in a similar diet was 85 per cent digested. In both instances the total carbohydrate was found to be practically completely digested.

Additional evidence regarding the effect on digestibility of including bran in flour is available in the reports of several investigators. Inasmuch as the experimental conditions employed in the tests of the digestibility of wheat flours made by the European investigators were not uniform, it is perhaps not possible to make as direct comparisons as in the case of the American studies. In general, considering the results of these investigations as a whole, it is apparent that the protein of flours containing a relatively small proportion of bran is more completely digested than the protein present in flours which contain a large proportion of bran.

In order to secure additional evidence regarding the effect on digestibility of including bran in flour Snyder[3] conducted two series of three digestion experiments each comparing digestibility of the protein of straight-grade flour and the digestibility of the protein of the same flour to which he added 14 per cent of finely ground bran (the amount of bran which he assumed to be normally present in graham flour). His results were as follows: The digestibility of bread from the flour with the bran was for protein 85.9 per cent

[1] Jour. Hyg. [Cambridge], 12 (1912), No. 2, pp. 132, 134.

[2] Skand. Arch. Physiol., 33 (1916), pp. 263–290; abst. in Chem. Abs., 12 (1918), No. 1, p. 54.

[3] U. S. Dept. Agr., Office Expt. Stas. Bul. 156 (1903–1905), p. 42.

(83.2 per cent, 84.4 per cent, and 90 per cent) and for carbohydrates 93.4 per cent (93 per cent, 92.8 per cent, and 94.3 per cent) and the digestibility of bread from the same flour without the bran was for protein 90.9 per cent (90.2 per cent, 91.9 per cent, and 90.6 per cent), and for carbohydrates 97.7 per cent (96.7 per cent, 98.2 per cent, and 98.1 per cent). As noted by Snyder, "Subject No. 3 digested practically the same proportion of the protein from the flour with the bran as from that without it," and considering these data alone one could conclude that the digestibility of bran protein was 90 per cent. If, on the other hand, the figures reported for subject No. 2 for the digestibility of protein of flour with bran, 84.4 per cent, and without bran, 91.9 per cent, are considered alone, the calculated digestibility of bran protein would be approximately 39 per cent. In general, however, the average values obtained in these tests for the digestibility of the mixture of white and bran flours, 85.9 per cent for the protein and 93.4 per cent for the carbohydrate, as compared with the digestibility of white flour alone, 90.9 per cent for protein and 97.7 per cent for carbohydrate, are in agreement with those obtained in the earlier studies of the digestibility of white and graham flours and indicate that the addition of bran, even if finely ground, to flour lowers the digestibility of the flour.

It is very generally believed that the difference in the digestibility of the protein and carbohydrate contained in graham flour and white flour is due to relative insolubility of bran cellulose in the human intestinal juices. That there is experimental evidence to substantiate such a theory is indicated by results of digestion experiments in which the crude fiber present in the foods and feces was studied.

Prausnitz[1] reports that the crude fiber of wheat bread is 53 per cent (52.6 per cent and 53.4 per cent) digested. This value, 53 per cent, is somewhat lower than the figures obtained by other investigators for the digestibility of the crude fiber of fruits and vegetables. In 30 digestion experiments conducted by Jaffa[2] to determine the digestibility of common fruits and nuts he found that on an average the crude fiber was 78.54 per cent digested. Constantinidi[3] states that the crude fiber of potatoes is 79 per cent digested. As the result of two experiments Weiske[4] concludes that the crude fiber of a diet of celery, cabbage, and carrots is 55 per cent (63 per cent and 47 per cent) digested. Bryant and Milner[5] report that the crude fiber of green corn is 60 per cent digested, that of potatoes 74 per cent, that of cabbage 77 per cent, that of beets 88 per cent, and that of apple

[1] Ztschr. Biol., 30 (1894), p. 350.
[2] U. S. Dept. Agr., Office Expt. Stas. Bul. 132 (1901–2), p. 69.
[3] Ztschr. Biol., 23 (1887), p. 452.
[4] Ztschr. Biol., 6 (1870), pp. 456–466.
[5] Amer. Jour. Physiol., 10 (1903), No. 2, p. 97.

sauce 95 per cent digested. As a rule cellulose of fruits and vegetables seems to interfere with their digestion to a limited extent only.

In grains, on the other hand, the cellulose forms the hard dry envelope and is much more impervious to the action of the digestive juices. With this fact in mind Finkler[1] attempted to devise a process for milling wheat which would render the bran more digestible and which would liberate the protein inclosed within the cellulose walls. He recommends the milling of wheat in a solution of sodium chlorid or a solution of sodium chlorid containing lime. He states that artificial digestion experiments show the protein of the "finalmehl" obtained by this process is as completely digested as the protein of white flour.

While a consideration of the results of the numerous digestion experiments made with different types of wheat flours leads to the conclusion that wheat bran is not as well assimilated as the interior portion of the wheat kernel, a review of the literature has failed to reveal any data on the digestibility of wheat bran when eaten in a diet which did not contain any portion of the remainder of the wheat kernel. It would seem that definite data regarding the digestibility of wheat bran when eaten in a diet containing no wheat flour are of material value in connection with the consideration of the effect of different percentages of milling of wheat upon the digestibility of the protein and carbohydrate contained in the resulting flours, and it was for the purpose of securing such data that the experiments here reported were undertaken.

METHODS OF PROCEDURE.

The methods employed in this investigation, especially the way the bran was prepared for eating, were essentially the same as those followed in experiments to determine the digestibility of nonsaccharine grain sorghums and millets.

In the investigations previously reported in which the digestibility of bran has been considered, the bran was referred to as "fine bran" or "very fine bran," but in the majority of instances no definite data are given regarding the coarseness or fineness of the bran used, and, accordingly, it is impossible to make a direct comparison of the results of the different studies.

In the study here reported the size of the bran particles received special attention, both fine and coarse bran being included in the tests, in order to determine the effect of this factor upon laxative properties. An ordinary commercial wheat bran secured in the open market was ground until relatively fine in the experimental mills of the Bureau of Chemistry. On bolting, all the ground bran passed

[1] Jour. Roy. Inst. Pub. Health, 19 (1911), No. 4, pp. 193–199, pls. 2.

through the 20-mesh sieve, 68 per cent remained on the 40-mesh sieve, 20 per cent remained on the 70-mesh sieve, 4 per cent remained on the 90-mesh sieve, 2 per cent remained on the 109-mesh sieve, and the remainder, 6 per cent, passed through the 109-mesh sieve. Two series of experiments were conducted, one with the ground bran described above and referred to in this paper as "fine wheat bran" and one series with unground bran in the form of "flakes" which were a part of the lot from which the fine wheat bran was prepared. The test periods were of 3-days' or 9-meals' duration. The urine was not collected and no attempt was made to maintain a nitrogen equilibrium, or uniform body weights. The feces were separated in the usual way by means of pulverized charcoal taken in gelatin capsules with the first meal of the test period and the first meal following the period. The foods and feces were analyzed by the usual chemical methods.

SUBJECTS.

Five different subjects assisted in this investigation and with the exception of one subject (P. K.) all took part in the two series of tests which were made. These subjects, students in medical or dental schools whose ages varies from about 20 to over 40 years, were so chosen as to be fairly typical of the average person of this period of life. While all were young men of normal appetites and to all appearances of good health, they were of quite different temperaments. Subject A. J. H., a strong, vigorous young man who had served one or two enlistments in the U. S. Army and who had seen service in the Philippines, possessed a particularly hearty appetite. Subject P. K., on the other hand, a man of over 40 years of age, took little more than necessary exercise, was studiously inclined, had a tendency toward constipation, and would be very properly classed as of sedentary habits. The other three subjects, while not representing such direct contrasts, were, nevertheless, not in the least alike as regards food habits, and kinds and amounts of exercise taken, although they were of about the same size and age.

All the subjects were instructed to submit a report of their physical condition during the test periods. They were also instructed to observe special care in reserving any uneaten portion of the diet and in the separation and collection of the feces resulting from the experimental diet.

EXPERIMENTAL DIET.

Since information regarding the digestibility of the protein supplied by wheat bran was especially desired, the diet was so chosen that the accessory foods should contain a minimum of protein and at the same time should not be totally different from an ordinary simple mixed diet possessing some variety. The experimental diet con-

sisted of a bran bread as the principal food, with enough accessory foods to make the diet tolerable and reasonably palatable, namely, boiled and mashed Irish potatoes (in limited quantities), fruit, butter, sugar, and tea or coffee.

The bran bread was prepared daily. A sufficient quantity of potatoes to supply all the subjects for the entire test period was boiled, mashed, and uniformly mixed at the beginning of the period. The fruit (oranges), butter, and sugar were purchased in the open market. The bran bread was made by the following recipe, which as will be noted contains some ginger and molasses. These materials were added primarily to make the bran more palatable and to mask its nature somewhat.

BRAN BREAD.

15 cups bran.
3¾ teaspoons soda.
1⅞ cups molasses.
3¾ teaspoons salt.
5 teaspoons ginger.
1 scant cup lard.
1¾ quarts hot water.

The lard was added to the hot water and the mixture added to the other ingredients, after which the whole was uniformly mixed. The bread was baked about 1½ hours. Since the bran contained no glutinous material to serve as a binder, the bread did not rise well and tended to crumble.

The digestibility of the protein and carbohydrate of the bran alone has been estimated by making allowance for the undigested protein and carbohydrate resulting from the accessory foods. In estimating the digestibility of bran alone by the method which has been outlined in full in earlier publications[1] it has been assumed, as a result of averaging the results of earlier experimental data, that the digestibility of the accessory foods is as follows: The protein of potatoes, 83 per cent[2]; of butter, 97 per cent[2]; and of fruit, 85 per cent[2]; while the digestibility of carbohydrate in potatoes, fruit, and sugar, is 95 per cent,[2] 90 per cent,[2] and 98 per cent,[2] respectively.

The details of the digestion experiments are recorded in the following tables, which include the kind, amount, and total weight of different foods eaten by each subject, the weight of the various constituents of the foods, the weight of the feces, the amount of food utilized, the coefficients of digestibility of the entire ration, and the estimated digestibility of the bread alone.

EXPERIMENTS WITH FINE WHEAT BRAN.

While the seven experiments which were made with fine bran were not all carried on at the same time, the subjects and experimental

[1] U. S. Dept. Agr. Buls. 470 (1916), p. 7; 525 (1917), p. 4.
[2] Connecticut Storrs Sta. Rpt. 1899, p. 104.

conditions were the same for the two groups, experiments Nos. 417, 418, and 420 and experiments Nos. 460, 461, 462, and 463. The following table reports the results of these experiments:

Data of digestion experiments with fine wheat bran in a simple mixed diet.

Experiments, subjects, and diet.	Weight of foods.	Constituents of foods.				
		Water.	Protein.	Fat.	Carbohydrates.	Ash.
Experiment No. 417, subject D.G.G.:	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Bread made of fine bran	1,714.0	796.3	93.2	138.2	596.5	89.8
Potato	568.0	428.8	14.2	0.6	118.7	5.7
Fruit	852.0	770.9	2.1	2.7	74.7	1.6
Butter	524.0	57.7	5.2	445.4	.....	15.7
Sugar	134.0	.....	.....	.....	134.0	.....
Total food consumed	3,792.0	2,053.7	114.7	586.9	923.9	112.8
Feces	438.0	.....	79.3	37.0	267.6	54.1
Amount utilized	.....	.....	35.4	549.9	656.3	58.7
Digestibility of entire ration (per cent)	.....	.....	30.9	93.7	71.0	52.0
Estimated digestibility of bran alone (per cent)	.....	.....	18.0	.....	38.4	.....
Experiment No. 418, subject A.J.H.:						
Bread made of fine bran	1,495.0	694.6	81.3	120.5	520.3	78.3
Potato	588.0	443.9	14.7	.6	122.9	5.9
Fruit	771.0	697.6	1.9	2.4	67.6	1.5
Butter	482.0	53.0	4.8	409.7	.....	14.5
Sugar	142.0	.....	.....	.....	142.0	.....
Total food consumed	3,478.0	1,889.1	102.7	533.2	852.8	100.2
Feces	471.0	.....	85.0	196.3	127.0	62.7
Amount utilized	.....	.....	17.7	336.9	725.8	37.5
Digestibility of entire ration (per cent)	.....	.....	17.2	63.2	85.1	37.4
Estimated digestibility of bran alone (per cent)	.....	.....	(1)	.....	69.2	.....
Experiment No. 419, subject R.L.S.:						
Bread made of fine bran	1,372.0	637.4	74.6	110.6	477.5	71.9
Potato	497.0	375.2	12.4	.5	103.9	5.0
Fruit	807.0	730.2	2.0	2.5	70.8	1.5
Butter	282.0	31.0	2.8	239.7	.....	8.5
Sugar	78.0	.....	.....	.....	78.0	.....
Total food consumed	3,036.0	1,773.8	91.8	353.3	730.2	86.9
Feces	440.0	.....	90.2	47.0	246.0	56.8
Amount utilized	.....	.....	1.6	306.3	484.2	30.1
Digestibility of entire ration (per cent)	.....	.....	1.7	86.7	66.3	34.6
Estimated digestibility of bran alone (per cent)	.....	.....	(1)	.....	28.8	.....
Experiment No. 420, subject O.E.S.:						
Bread made of fine bran	1,399.0	650.0	76.1	112.8	486.8	73.3
Potato	520.0	392.6	13.0	.5	108.7	5.2
Fruit	876.0	792.6	2.2	2.7	76.8	1.7
Butter	280.0	30.8	2.8	238.0	.....	8.4
Sugar	196.0	.....	.....	.....	196.0	.....
Total food consumed	3,271.0	1,866.0	94.1	354.0	868.3	88.6
Feces	410.0	.....	81.2	52.3	224.8	51.7
Amount utilized	.....	.....	12.9	301.7	643.5	36.9
Digestibility of entire ration (per cent)	.....	.....	13.7	85.2	74.1	41.6
Estimated digestibility of bran alone (per cent)	.....	.....	(1)	.....	37.6	.....

[1] Negative results, the fecal protein exceeding that in bran eaten.

Data of digestion experiments with fine wheat bran in a simple mixed diet—Con.

Experiments, subjects, and diet.	Weight of foods.	Constituents of foods.				
		Water.	Protein.	Fat.	Carbohydrates.	Ash.
Experiment No. 460, subject D.G.G.:	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Bread made of fine bran	1,483.0	670.2	84.4	142.5	521.6	64.3
Potato	394.0	297.5	9.9	.4	82.3	3.9
Apple	738.0	624.3	3.0	3.7	104.8	2.2
Orange	281.0	244.2	2.2	0.6	32.6	1.4
Butter	258.0	28.4	2.6	219.3	.....	7.7
Sugar	108.0	.....	.....	.....	108.0	.....
Total food consumed	3,262.0	1,864.6	102.1	366.5	849.3	79.5
Feces	195.0	.....	39.0	16.3	117.1	22.6
Amount utilized	.....	.....	63.1	350.2	732.2	56.9
Digestibility of entire ration (per cent)	.....	.....	61.8	95.6	86.2	71.6
Estimated digestibility of bran alone (per cent)	.....	.....	56.8	.....	71.0	.....
Experiment No. 461, subject A.J.H.:						
Bread made of fine bran	997.0	450.5	56.7	95.8	350.7	43.3
Potato	503.0	379.8	12.6	.5	105.1	5.0
Apple	420.0	355.3	1.7	2.1	59.6	1.3
Orange	575.0	499.7	4.6	1.1	66.7	2.9
Butter	390.0	42.9	3.9	331.5	.....	11.7
Sugar	49.0	.....	.....	.....	49.0	.....
Total food consumed	2,934.0	1,728.2	79.5	431.0	631.1	64.2
Feces	169.0	.....	37.6	18.6	91.8	21.0
Amount utilized	.....	.....	41.9	412.4	539.3	43.2
Digestibility of entire ration (per cent)	.....	.....	52.7	95.7	85.5	67.3
Estimated digestibility of bran alone (per cent)	.....	.....	43.2	.....	67.5	.....
Experiment No. 462, subject P.K.:						
Bread made of fine bran	1,505.0	680.1	85.7	144.6	529.3	65.3
Potato	518.0	391.1	12.9	.5	108.3	5.2
Apple	759.0	642.1	3.0	3.8	107.8	2.3
Orange	332.0	288.5	2.6	0.7	38.5	1.7
Butter	238.0	26.2	2.4	202.3	.....	7.1
Sugar	33.0	.....	.....	.....	33.0	.....
Total food consumed	3,385.0	2,028.0	106.6	351.9	816.9	81.6
Feces	237.0	.....	46.0	23.2	138.0	29.8
Amount utilized	.....	.....	60.6	328.7	678.9	51.8
Digestibility of entire ration (per cent)	.....	.....	56.8	93.4	83.1	63.5
Estimated digestibility of bran alone (per cent)	.....	.....	50.1	.....	65.3	.....
Experiment No. 463, subject R.L.S.:						
Bread made of fine bran	1,255.0	567.1	71.4	120.6	441.4	54.5
Potato	396.0	299.0	9.9	.4	82.7	4.0
Apple	657.0	555.8	2.6	3.3	93.3	2.0
Orange	166.0	144.3	1.3	.3	19.3	.8
Butter	133.0	14.6	1.3	113.1	.....	4.0
Sugar	44.0	.....	.....	.....	44.0	.....
Total food consumed	2,651.0	1,580.8	86.5	237.7	680.7	65.3
Feces	154.0	.....	33.9	12.8	88.3	19.0
Amount utilized	.....	.....	52.6	224.9	592.4	46.3
Digestibility of entire ration (per cent)	.....	.....	60.8	94.6	87.0	70.9
Estimated digestibility of bran alone (per cent)	.....	.....	55.7	.....	74.7	.....
Average food consumed per subject per day	1,075.4	616.0	32.4	133.9	264.7	28.3

Summary of digestion experiments with fine wheat bran in a simple mixed diet.

Experiment No.	Subject.	Digestibility of entire ration.				Estimated digestibility of protein of bran alone.	Estimated digestibility of carbohydrate of bran alone.
		Protein.	Fat.	Carbohydrate.	Ash.		
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
417	D. G. G.	30.9	93.7	71.0	52.0	18.0	38.4
418	A. J. H.	17.2	63.2	85.1	37.4	(1)	69.2
419	R. L. S.	1.7	86.7	66.3	34.6	(1)	28.8
420	O. E. S.	13.7	85.2	74.1	41.6	(1)	37.6
460	D. G. G.	61.8	95.6	86.2	71.6	56.8	71.0
461	A. J. H.	52.7	95.7	85.5	67.3	43.2	67.5
462	P. K.	56.8	93.4	83.1	63.5	50.1	65.3
463	R. L. S.	60.8	94.6	87.0	70.9	55.7	74.7
Average		37.0	88.5	79.8	54.9	44.7	56.6

[a] Negative value, fecal protein exceeding that of bran eaten. Not included in average.

The subjects ate on an average 32 grams of protein, 134 grams of fat, and 265 grams of carbohydrate daily, which taken together furnished in round numbers 2,400 calories. The diet was somewhat low in energy for active young men and decidedly low in protein. With the diet followed, a low protein consumption is almost unavoidable, for it was hardly possible to eat more of the bran bread than was consumed (approximately 420 grams daily), and in order that the bran might supply the major portion of the protein intake it was not desirable to increase the amount of potato taken with the bread.

The average coefficients of digestibility of the diet as a whole were found to be for protein 37 per cent, for fat 88.5 per cent, and for carbohydrate 79.8 per cent. Excluding experiments Nos. 417, 418, 419, and 420, in which the digestibility of protein was very low, the average coefficient of digestibility for protein becomes 58 per cent. Excluding experiment No. 417 and leaving out the negative values it becomes 51.4 per cent for the protein of bran alone.

As regards the laxative properties of the diet, records kept by the subjects show a variation from "condition entirely normal" to "bowels very loose." In three of the experiments, Nos. 418, 419, and 420, the amount of bran protein excreted in the feces exceeded that supplied by the bran eaten. In these cases, and also in experiment No. 417, where the digestibility was very low as compared with other tests, it might be assumed that an increase of peristalsis has effected a greatly decreased absorption, or that for some cause there has been an increase in the elimination of metabolic nitrogen through the intestines.

The figure 44.7 per cent reported for the digestibility of bran protein results from averaging the figures obtained in five tests, while the figure 56.6 per cent reported for bran carbohydrate results from averaging eight experiments. The figure 44.7 per cent agrees closely with that obtained by Pannwitz,[1] who found that the protein of finely ground bran was 43.7 per cent digested. However, the value 51.4 per cent obtained by including only three tests is considerably higher than his figure. The figure 56.6 per cent for the digestibility of bran carbohydrate is materially lower than that of the carbohydrate of cereal flours or meals or the carbohydrate of the average mixed diet, a fact in accord with data reported by other observers.

The figure 88.5 per cent obtained for the digestibility of the total fat of the diet is of interest. Except for the very little in the bran and in the potato and fruit the fat consumed consisted wholly of lard used in the preparation of the bread and butter eaten with the bread and potato. The digestibility of lard[2] had been found to be 97 per cent. In similar experiments[2] the digestibility of butter was found to be 97 per cent, and when it was included in a diet of meat loaf (containing hard palates of cattle), potato, crackers, sugar, and tea or coffee, the butter[3] was 95 per cent digested. In other experiments in which the diet consisted of bread, potato, fruit, butter (which supplied practically all the fat of the diet), sugar, and tea or coffee, the butter[4] was over 95 per cent digested. In more recent experiments in which butter[5] was eaten in conjunction with dasheen, milk, fruit, and tea or coffee, butter was over 96 per cent digested. It perhaps may be possible that the bran stimulated peristaltic action to such an extent that the fats, lard, and butter did not remain in the alimentary tract long enough to become as completely absorbed as they otherwise would.

EXPERIMENTS WITH UNGROUND WHEAT BRAN.

Seven experiments were made to determine the digestibility of the protein supplied by unground bran (flakes). The experiments were made in two groups, the first comprising experiments Nos. 409, 411, and 412 during the period March 13 to 16, inclusive, and the second experiments Nos. 436, 437, 438, and 439 during the period May 8 to 11, inclusive. With one exception the same subjects assisted in both groups of experiments, and uniform experimental conditions

[1] Nährwerth des Soldatenbrotes, Inaug Diss., Berlin, 1898, p. 123.
[2] U. S. Dept. Agr. Bul. 310 (1915), p. 21.
[3] U. S. Dept. Agr., Jour. Agr. Research, 6 (1916), No. 17, p. 647.
[4] U. S. Dept. Agr. Bul. 525 (1917), p. 8.
[5] U. S. Dept. Agr. Bul. 612 (1917), p. 8.

were maintained for all the experiments. The data resulting from these tests are summarized in the tables which follow:

Data of digestion experiments with coarse wheat bran in a simple mixed diet.

Experiments, subjects, and diet.	Weight of foods.	Constituents of foods.				
		Water.	Protein.	Fat.	Carbohydrates.	Ash.
Experiment No. 409, subject to D.G.G.:	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Bread made with unground bran	1,260.0	660.4	55.1	105.2	373.3	66.0
Potato	546.0	412.2	13.7	.5	114.1	5.5
Fruit	784.0	707.8	2.0	2.5	70.2	1.5
Butter	199.0	21.9	2.0	169.1	.....	6.0
Sugar	142.0	.....	.....	.....	142.0	.....
Total food consumed	2,931.0	1,802.3	72.8	277.3	699.6	79.0
Feces	236.0	.....	50.4	17.8	140.3	27.5
Amount utilized	.....	.....	22.4	259.5	559.3	51.5
Digestibility of entire ration (per cent)	.....	.....	30.8	93.6	79.9	65.2
Estimated digestibility of bran alone (per cent)	.....	.....	13.4	.....	45.4	.....
Experiment No. 410, subject A.J.H.:						
Bread made with unground bran	1,107.0	580.2	48.4	92.4	328.0	58.0
Potato	509 0	384.3	12.7	.5	106.4	5.1
Fruit	688.0	621.1	1.7	2.2	61.7	1.3
Butter	233.0	25.6	2.3	198.1	.....	7.0
Sugar	77.0	.....	.....	.....	77.0	.....
Total food consumed	2,614.0	1,611.2	65.1	293.2	573.1	71.4
Feces	256.0	.....	66.2	32.9	121.6	35.3
Amount utilized	.....	.....	.....	260.3	451.5	36.1
Digestibility of entire ration (per cent)	.....	.....	.....	88.8	78.8	50.6
Estimated digestibility of bran alone (per cent)	.....	.....	(1)	.....	45.8	.....
Experiment No. 411, subject R.L.S.:						
Bread made with unground bran	1,335.0	699.7	58.3	111.5	395.6	69.9
Potato	361.0	272.6	9.0	.4	75.4	3.6
Fruit	817.0	737.6	2.0	2.6	73.2	1.6
Butter	149.0	16.4	1.5	126.6	.....	4.5
Sugar	208.0	.....	.....	.....	208.0	.....
Total food consumed	2,870.0	1,726.3	70.8	241.1	752.2	79.6
Feces	226.0	.....	63.0	17.4	114.5	31.1
Amount utilized	.....	.....	7.8	223.7	637.7	48.5
Digestibility of entire ration (per cent)	.....	.....	11.0	92.8	84.8	60.9
Estimated digestibility of bran alone (per cent)	.....	.....	(1)	.....	59.4	.....
Experiment No. 412, subject O.E.S.:						
Bread made with unground bran	1,119.0	586.5	48.9	93.4	331.6	58.6
Potato	507.0	382.8	12.7	.5	105.9	5.1
Fruit	586.0	529.0	1.5	1.9	52.5	1.1
Butter	66.0	7.3	0.6	56.1	.....	2.0
Sugar	297.0	.....	.....	.....	297.0	.....
Total food consumed	2,575.0	1,505.6	63.7	151.9	787.0	66.8
Feces	167.0	.....	33.9	10.3	97.8	25.0
Amount utilized	.....	.....	29.8	141.6	689.2	41.8
Digestibility of entire ration (per cent)	.....	.....	46.8	93.2	87.6	62.6
Estimated digestibility of bran alone (per cent)	.....	.....	35.6	.....	60.3	.....

[1] Negative results, fecal protein exceeding that in bran eaten.

Data of digestion experiments with coarse wheat bran in a simple mixed diet—Continued.

Experiments, subjects, and diet.	Weight of foods.	Constituents of foods.				
		Water.	Protein.	Fat.	Carbohydrates.	Ash.
Experiment No. 436, subject D.G.G.:	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Bread made with unground bran	1,454.0	696.5	69.9	147.1	462.8	77.7
Potato	438.0	330.7	11.0	.4	91.5	4.4
Fruit	700.0	607.6	2.1	2.8	85.4	2.1
Butter	418.0	46.0	4.2	355.3	.....	12.5
Sugar	164.0	.....	.....	.....	164.0	.....
Total food consumed	3,174.0	1,680.8	87.2	505.6	803.7	96.7
Feces	297.0	.....	63.3	26.6	170.1	37.0
Amount utilized	.....	.....	23.9	479.0	633.6	59.7
Digestibility of entire ration (per cent)	.....	.....	27.4	94.7	78.8	61.7
Estimated digestibility of bran alone (per cent)	.....	.....	16.7	.....	41.5	.....
Experiment No. 437, subject A.J.H.:						
Bread made with unground bran	1,055.0	505.4	50.7	106.8	335.8	56.3
Potato	466.0	351.8	11.6	.5	97.4	4.7
Fruit	630.0	546.8	1.9	2.5	76.9	1.9
Butter	387.0	42.6	3.9	328.9	.....	11.6
Sugar	103.0	.....	.....	.....	103.0	.....
Total food consumed	2,641.0	1,446.6	68.1	438.7	613.1	74.5
Feces	140.0	.....	30.4	18.8	69.4	21.4
Amount utilized	.....	.....	37.7	419.9	543.7	53.1
Digestibility of entire ration (per cent)	.....	.....	55.4	95.7	88.7	71.3
Estimated digestibility of bran alone (per cent)	.....	.....	49.7	.....	72.1	.....
Experiment No. 438, subject R.L.S.:						
Bread made with unground bran	1,129.0	540.8	54.3	114.2	359.4	60.3
Potato	420.0	317.1	10.5	.4	87.8	4.2
Fruit	684.0	593.7	2.1	2.7	83.4	2.1
Butter	99.0	10.9	1.0	84.1	.....	3.0
Sugar	88.0	.....	.....	.....	88.0	.....
Total food consumed	2,420.0	1,462.5	67.9	201.4	618.6	69.6
Feces	183.0	.....	39.5	17.4	100.3	25.8
Amount utilized	.....	.....	28.4	184.0	518.3	43.8
Digestibility of entire ration (per cent)	.....	.....	41.8	91.4	83.8	62.9
Estimated digestibility of bran alone (per cent)	.....	.....	31.1	.....	58.4	.....
Experiment No. 439, subject O.E.S.:						
Bread made with unground bran	1,009.0	483.3	48.5	102.1	321.2	53.9
Potato	439.0	331.4	11.0	.4	91.8	4.4
Fruit	675.0	585.9	2.0	2.7	82.4	2.0
Butter	285.0	31.4	2.8	242.2	.....	8.6
Sugar	208.0	.....	.....	.....	208.0	.....
Total food consumed	2,616.0	1,432.0	64.3	347.4	703.4	68.9
Feces	173.0	.....	40.3	19.0	89.6	24.1
Amount utilized	.....	.....	24.0	328.4	613.8	44.8
Digestibility of entire ration (per cent)	.....	.....	37.3	94.5	87.3	65.0
Estimated digestibility of bran alone (per cent)	.....	.....	21.6	.....	60.7	.....
Average food consumed per subject per day	915.6	526.5	23.6	103.0	237.0	25.5

Summary of digestion experiments with wheat bran in a simple mixed diet.

Experiment No.	Subject.	Digestibility of entire ration.				Estimated digestibility of protein of bran alone.	Estimated digestibility of carbohydrate of bran alone.
		Protein.	Fat.	Carbohydrate.	Ash.		
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
409	D. G. G.	30.8	93.6	79.9	65.2	13.4	45.4
410	A. J. H.	(1)	88.8	78.8	50.6	(2)	45.8
411	R. L. S.	11.0	92.8	84.8	60.9	(2)	59.4
412	O. E. S.	46.8	93.2	87.6	62.6	35.6	60.3
436	D. G. G.	27.4	94.7	78.8	61.7	16.7	41.5
437	A. J. H.	55.4	95.7	88.7	71.3	49.7	72.1
438	R. L. S.	41.8	91.4	83.8	62.9	31.1	58.4
439	O. E. S.	37.3	94.5	87.3	65.0	21.6	60.7
Average		35.8	93.1	82.8	62.5	28.0	55.5

[1] Negative result, fecal protein exceeding that of diet.
[2] Negative result, fecal protein exceeding that of bran eaten. Not included in average.

On an average the food consumed by the subjects furnished 24 grams of protein, 103 grams of fat, and 237 grams of carbohydrate daily, with an average energy value of approximately 1,970 calories. Although the subjects ate, in round numbers, 400 grams of the bran bread daily, the total amount of protein supplied per day was small. However, it was desirable that bran should furnish the major portion of the protein, and so, as was the case in the experiments with finely ground bran, no attempt was made to increase the protein intake by increasing the amount of potato consumed with the coarse bran bread.

The coefficients of digestibility of the diet as a whole were 35.8 per cent for protein, 93.1 per cent for fat, and 82.8 per cent for carbohydrate. These values are, of course, lower than those which have been reported for an average mixed diet,[1] namely, 92 per cent for protein, 95 per cent for fat, and 97 per cent for carbohydrate.

It is of interest to compare the coefficients of digestibility of the fat of the diet, 93.1 per cent (practically all obtained from lard used in preparing the bread and butter eaten with the bread and potato), with the coefficient of digestibility, 97 per cent, found for both lard and butter in experiments previously reported.[2]

In experiment No. 410 a negative value was obtained for the digestibility of protein, the amount excreted in the feces exceeding the amount supplied by the diet. In experiments Nos. 409, 411, and 436 the coefficients of digestibility were decidedly lower than in the remaining tests. Excluding these low values the coefficient of digestibility of protein becomes 45.3 per cent. The average digestibility of the carbohydrate of the coarse bran, 55.5 per cent, closely approximates the value 56.6 per cent obtained in the tests with finely ground bran.

[1] Connecticut Storrs Sta. Rpt. 1901, p. 245.
[2] U. S. Dept. Agr. Bul. 310 (1915), pl. 21.

In computing the digestibility of bran protein negative results were obtained in experiments Nos. 410 and 411; that is, the fecal protein was greater than that supplied by the bran. In three of the remaining tests (experiments Nos. 409, 436, and 439) the values were decidedly lower than in the remaining tests. Omitting these low values the average coefficients of digestibility for bran becomes 38.8 per cent instead of 28 per cent.

The reports made by the subjects regarding their physical condition vary from "normal except for occasional slight pains in the stomach after eating" to "extreme laxative effect."

No definite relation was apparent between such observations and the coefficients of digestibility. It is also interesting to note that the subjects were all of the opinion that no differences with respect to laxative effect were noted in the tests with finely ground and with coarse bran.

GENERAL DISCUSSION.

The results of numerous studies conducted both in this country and abroad to determine the digestibility of wheat flours containing little, if any, bran as compared with the digestibility of flours containing all the bran normally present in the grain show that the protein and carbohydrate of flours from which the bran has been largely removed is more completely utilized by the human body than the protein and carbohydrate of flours prepared from the whole grain.

So far as can be learned, no studies have been made to determine the digestibility of wheat bran when eaten as a constituent of a diet which did not include the flour prepared from the remainder of the kernel. With the purpose of securing more data on the digestibility of wheat bran included in a diet from which all forms of wheat flour were excluded, two series of experiments were made, one with fine bran and one with coarse bran, the subjects and experimental conditions being alike for both series.

An average of 465 grams of fine bran bread, equivalent to 155 grams bran, and of 395 grams of coarse bran bread, equivalent to 132 grams bran, was eaten per man per day. The results of tests with fine bran indicate that the protein supplied by the bran was 44.7 per cent and the bran carbohydrate was 56.6 per cent digested, while the results of the tests with coarse bran indicate a digestibility of 28 per cent for the bran protein and 55.5 per cent for the bran carbohydrate. The result for the digestibility of fine bran protein is in agreement with the results of Pannwitz,[1] who found that the protein of fine rye bran was 43.68 per cent digested.

[1] Nährwerth des Soldatenbrotes, Inaug. Diss., Berlin, 1898, p. 100.

The digestibility of the protein of white flour obtained by averaging the results of the 31 tests reported in the United States Department of Agriculture investigations noted on page 4 is found to be 88.1 per cent. The digestibility of the protein of graham flour (representing the whole kernel) obtained by averaging the results of the 24 tests reported in the same investigations by the United States Department of Agriculture is found to be 76.9 per cent. If it is assumed that white flour contains 15.1 per cent[1] of protein which is 88.1 per cent digested and that fine bran contains 15.4 per cent[1] of protein which is 44.6 per cent digested, then by calculation the digestibility of the total protein supplied by a graham flour consisting of 72 per cent of white flour and the remainder of fine bran would be 75.8 per cent. It is an interesting coincidence that the value 75.8 per cent calculated for the digestibility of graham flour should agree so closely with the value 76.9 per cent obtained by averaging the results of the determination of the digestibility of protein of graham flour found in the 26 digestion experiments noted above.

The coefficients of digestibility of the diet as a whole (37 per cent for protein, 88.5 per cent for fat, and 79.8 per cent for carbohydrate, in the series in which fine bran was eaten, and 35.8 per cent for protein, 93.1 per cent for fat, and 82.8 per cent for carbohydrate, in the series in which coarse bran was eaten), are lower than the coefficients of digestibility, 92 per cent for protein, 95 per cent for fat, and 97 per cent for carbohydrate, reported[2] for the ordinary mixed diet. This indicates the way in which the rough, relatively indigestible bran influenced the digestibility of the entire diet. It is also possible that the bran stimulated peristaltic action to such an extent that the food materials were not as completely absorbed as is normally the case when they pass through the alimentary tract without increased peristalsis.

In general the amount of feces voided by the subjects during the tests with bran was larger than normal. This condition was noted by all the subjects regardless as to whether they were of active, athletic, or sedentary habits. Some of the subjects found the bran diets decidedly laxative. Little, if any, difference was noted by the subjects as a whole between the laxative effects of the fine and coarse brans.

It is hoped that the results of the experiments here reported when considered in connection with the available data on the digestibility of wheat will be of value in determining the most economical and physiologically efficient method of utilizing wheat for human food.

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 156 (1905), p. 14.
[2] Connecticut Storrs Sta. Rpt. 1901, p. 245.

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